RECENT BES RESULTS ON $\psi(3770)$ AND D MESON PRODUCTION AND DECAY*

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Using a data sample of 17.7 pb^{-1} collected at 3.773 GeV with the BES-II detector at the BEPC, the cross sections for $D^0\overline{D}^0$ and D^+D^- productions at 3.773 GeV have been measured. From the data sample about 33 pb^{-1} taken around 3.773 GeV, $7696 \pm 199 \pm 369$ and $5381 \pm 128 \pm 188$ singly-tagged neutral and charged D mesons are accumulated, respectively. In the system recoiling against the singly-tagged charged D sample, 3 purely leptonic decay events of $D^+ \to \mu^+\nu$ are observed, which yields the branching fraction to be $BF(D^+ \to \mu^+\nu) = (0.120^{+0.092+0.010}_{-0.063-0.009})\%$ and the decay constant $f_D = (365^{+121+32}_{-113-28})$ MeV. From the singly tagged D sample, the semileptonic decay branching fractions for $D^0 \to K^-e^+\nu$, $D^0 \to \pi^-e^+\nu$ and $D^+ \to \overline{K}^0e^+\nu$ are measured to be $BF(D^0 \to K^-e^+\nu_e) = (3.52 \pm 0.36 \pm 0.25)\%$, $BF(D^0 \to \pi^-e^+\nu_e) = (0.36 \pm 0.14 \pm 0.03)\%$ and $BF(D^+ \to \overline{K}^0e^+\nu_e) = (8.64 \pm 1.51 \pm 0.72)\%$. The vector form factors are determined to be $|f_+^K(0)| = 0.75 \pm 0.04 \pm 0.03$ and $|f_+^\pi(0)| = 0.76 \pm 0.15 \pm 0.06$. The ratio of the two form factors is extracted to be $|f_+^\pi(0)/f_+^K(0)| = 1.01 \pm 0.20 \pm 0.08$. The ratio of the decay widths is measured to be $\Gamma(D^0 \to K^-e^+\nu)/\Gamma(D^+ \to \overline{K}^0e^+\nu) = 1.04 \pm 0.21 \pm 0.08$. From the data sample of about 27 pb^{-1}, the evidence of $\psi(3770) \to J/\psi\pi^+\pi^-$ non-$D\overline{D}$ decay is observed. The branching fraction is determined to be $BF(\psi(3770) \to J/\psi\pi^+\pi^-) = (0.34 \pm 0.14 \pm 0.08)\%$, corresponding to the partial width of $\Gamma(\psi(3770) \to J/\psi\pi^+\pi^-) = (80 \pm 32 \pm 21)$ keV.

I. INTRODUCTION

At the center-of-mass energy of 3.773 GeV, the $\psi(3770)$ resonance is produced in e^+e^- annihilation, and the open charm pairs of $D^0\overline{D^0}$ and D^+D^- are mainly produced from $\psi(3770)$ decays. Taking the advantage of the $D\overline{D}$ production, we can use the single tag method to measure the cross sections for $D^0\overline{D}^0$, D^+D^- and $D\overline{D}$ productions at the energy of 3.773 GeV; using the double tag method we can measure some absolute decay branching fractions of neutral and charged D mesons.

In this paper, we report some preliminary results on measurement of the cross section for $D\overline{D}$ production, measurement of the decay constant f_D, measurements of the form factors $f_+^\pi(0)$ and $f_+^K(0)$ in the semileptonic decays of D^0 meson, measurement of the ratio of partial width $\frac{\Gamma(D^0 \to K^-e^+\nu)}{\Gamma(D^+ \to \overline{K}^0 e^+\nu)}$, and the evidence of $\psi(3770)$ decay to a non-$D\overline{D}$ final state.

II. CROSS SECTION FOR $D\overline{D}$ PRODUCTION

The data used in this analysis were collected at the center-of-mass energy of 3.773 GeV with the Beijing Spectrometer [1] at the Beijing Electron Positron Collider. The total integrated luminosity of the data is 17.7 pb^{-1}. The measurements of the cross sections for the $D^0\overline{D^0}$, D^+D^- and $D\overline{D}$ productions are made based on the analysis of singly tagged D^0 and D^+ samples. At center-of-mass energy $\sqrt{s} = 3.773$ GeV, the D^0 (Through this paper, charge conjugation is implied.) and D^+ are produced in pair via the process of

$$e^+e^- \to D^0\overline{D^0}, D^+D^-. \tag{1}$$

The totally observed number $N_{D^0_{tag}}$ ($N_{D^+_{tag}}$) of D^0 (D^+) mesons and the observed cross sections $\sigma^{obs}_{D^0\overline{D}^0}$ ($\sigma^{obs}_{D^+D^-}$)

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are related by a relation

$$\sigma^{obs}_{D^0\overline{D}^0} = \frac{N_{D^0_{tag}}}{2 \times L \times B \times \epsilon}, \quad (2)$$

and

$$\sigma^{obs}_{D^+D^-} = \frac{N_{D^+_{tag}}}{2 \times L \times B \times \epsilon}, \quad (3)$$

where L is the integrated luminosity of the data set used in the analysis, B is the well-known branching fractions [2] for decay modes in question, and ϵ is the Monte Carlo efficiency for reconstruction of this decay mode in the data analysis.

In the measurements of the cross sections, the singly tagged neutral and charged D meson are made by fully reconstructing one D meson from the $D^0\overline{D}^0$ (D^+D^-) pair in the invariant mass spectra of the daughter particles from the D decay. Taking the advantage of the $D\overline{D}$ pair production, we use kinematic fit to some specific particle combinations to improve the ratio of signal to noise and mass resolution in the invariant mass spectrum. The distributions in the fitted masses of $Km\pi$ ($m = 1$, or 2, or 3) combinations, which are calculated using the fitted momentum vectors from the kinematic fit, are shown in Fig. 1. The signals for neutral and charged D mesons production are clearly observed in the fitted mass spectra as shown in the Fig. 1.

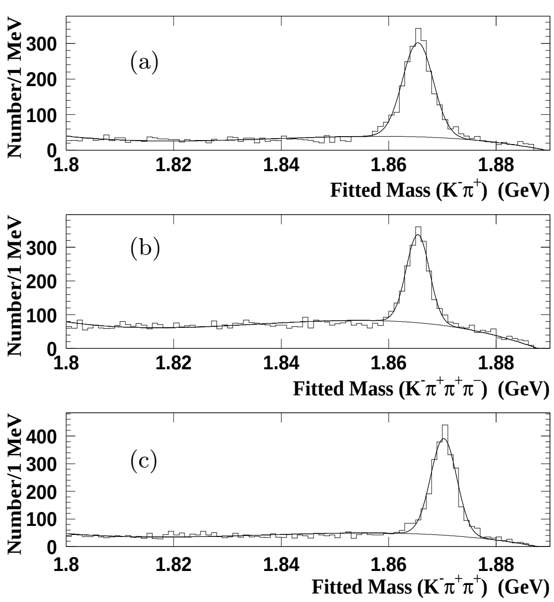

FIG. 1: Distribution of the fitted masses of the $Km\pi$ (m=1, or 2, or 3) combinations for three singly tagged modes, where Fig. (a) and Fig. (b) are for the decay modes of $D^0 \to K^-\pi^+$ and $D^0 \to K^-\pi^+\pi^+\pi^-$, respectively, and the Fig. (c) is for the decay mode of $D^+ \to K^-\pi^+\pi^+$.

We measure the observed cross sections for D^+D^-, $D^0\overline{D^0}$ and $D\overline{D}$ productions to be

$$\sigma^{obs}_{D^+D^-} = (2.52 \pm 0.07 \pm 0.24) \text{ nb},$$

$$\sigma^{obs}_{D^0\bar{D}^0} = (3.26 \pm 0.09 \pm 0.25) \text{ nb}.$$

$$\sigma^{obs}_{D\bar{D}} = (5.78 \pm 0.11 \pm 0.45) \text{ nb}.$$

After correcting to the effect of Initial State Radiation and the vacuum polarization, we obtain the tree level cross sections to be,

$$\sigma^{tree}_{D^+D^-} = (3.23 \pm 0.09 \pm 0.34) \text{ nb},$$

$$\sigma^{tree}_{D^0\bar{D}^0} = (4.18 \pm 0.12 \pm 0.37) \text{ nb}.$$

$$\sigma^{tree}_{D\bar{D}} = (7.42 \pm 0.14 \pm 0.67) \text{ nb}.$$

III. PURELY LEPTONIC DECAYS OF $D^+ \to \mu^+\nu$ AND DECAY CONSTANT f_D

The D^- mesons are reconstructed in $K^+\pi^-\pi^-$, $K^0\pi^-$, K^0K^-, $K^+K^-\pi^-$, $K^0\pi^-\pi^-\pi^+$, $K^0\pi^-\pi^0$, $K^+\pi^-\pi^-\pi^0$, $K^+\pi^+\pi^-\pi^-\pi^-$ and $\pi^-\pi^-\pi^+$ modes with sub-resonances decaying as $K^0_S \to \pi^+\pi^-$, and $\pi^0 \to \gamma\ \gamma$. Fig. 2 shows the distributions in the fitted masses of $mKn\pi$ ($m = 1, 2$ and the $n = 1, 2, 3$) combinations. The signals for D^- production are clearly observed in the fitted mass spectra as shown in the Fig. 2. We accumulate $5381 \pm 128 \pm 188$ singly tagged D^- mesons in total.

The system recoiling against the singly tagged D^- in each of the events as shown in the Fig. 2 are examined for consistency with the decay $D^+ \to \mu^+\nu$. It is required that there is a singly charged track and $|\cos\theta| < 0.68$, where the θ is the polar angle of the charged track. There must be hits in the muon counter which are well associate within $\pm 4\sigma$ with the tracks in transverse projection and Z direction; the required number of hits is momentum dependent.

For the candidate events, no isolated photon is allowed to be present, where the isolated photon is defined as an electromagnetic shower with the energy being greater than 100 MeV and the direction of the shower development separated by at least 20 degrees from the direction of the nearest charged track. Since there is a missing neutrino in the purely leptonic decay event, the event should be characteristic with missing energy E_{miss} and missing momentum P_{miss} carried by the neutrino. For the typical purely leptonic decay events, the difference between the E_{miss} and the P_{miss} should be around zero. We define the deference to be

$$U_{miss} = E_{miss} - P_{miss}.$$

To select the purely leptonic decay events from the singly tagged D^- sample, we require the U_{miss} of the candidate

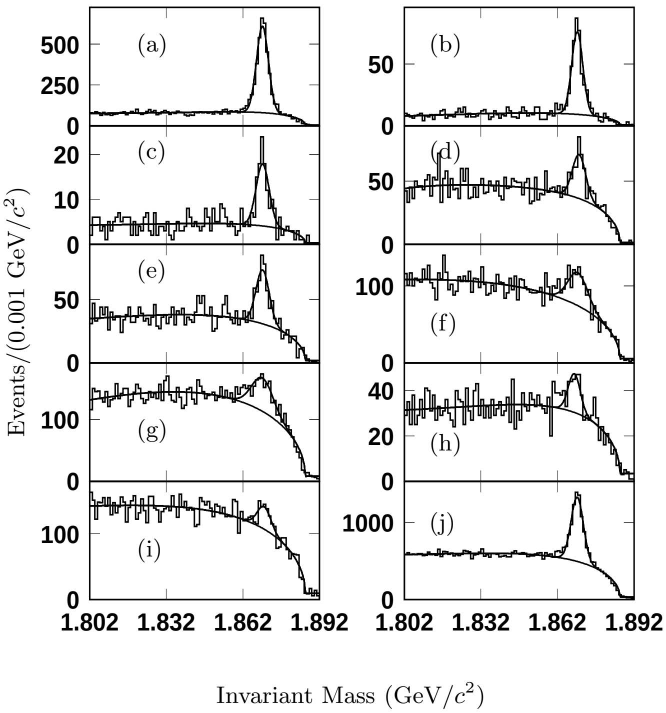

FIG. 2: Distribution of the fitted masses of the $nKm\pi$ (m=0 or 1 or 2, n=1 or 2 or 3 or 4) combinations for the 9 single tag modes; (a), (b), (c), (d), (e), (f), (g), (h) and (i) are for the modes of $D^- \to K^+\pi^-\pi^-$, $D^- \to K^0\pi^-$, $D^- \to K^0K^-$, $D^- \to K^+K^-\pi^-$, $D^- \to K^0\pi^-\pi^-\pi^+$, $D^- \to K^0\pi^-\pi^0$, $D^- \to K^+\pi^-\pi^-\pi^0$, $D^- \to K^+\pi^+\pi^-\pi^-\pi^-$ and $D^- \to \pi^-\pi^-\pi^+$ respectively; (j) is the fitted masses of the $nKm\pi$ combinations for the 9 modes together.

events to be in the $\pm 3.0\sigma_{U_{miss}}$ region. We also require the momentum of the muon to be within the range of 0.780 GeV/c to 1.115 GeV/c. Three candidate events satisfy the selection criteria of the purely leptonic decay events. A detailed Monte Carlo study shows that there are 0.31 ± 0.16 background events in the 3 candidate events. The efficiency to reconstruct the purely leptonic decay events is 0.405 ± 0.011. These result the purely leptonic branching fraction to be

$$BF(D^+ \to \mu^+\nu) = (0.120^{+0.092+0.010}_{-0.063-0.009})\%,$$

and decay constant of

$$f_D = (365^{+121+32}_{-113-28}) \text{ MeV},$$

where the first errors are statistical and second systematic which arise from the uncertainties in the measured branching fraction, the CKM matrix element $|V_{cd}|$ and the lifetime of D^+; the systematic uncertainties in the measured branching fraction arise mainly from the uncertainties in the μ^+ identification, tracking efficiency, background subtraction and U_{miss} cut. The central value of the f_D is consistent with that measured with BES-I detector [3].

IV. SEMILEPTONIC DECAYS OF CHARGED AND NEUTRAL D MESONS

A. Branching fractions for $D^0 \to K^-e^+\nu$ and $D^0 \to \pi^-e^+\nu$

The singly tagged $\overline{D}^0$ mesons are obtained by reconstructing the four decay modes of $\overline{D}^0 \to K^+\pi^-$, $\overline{D}^0 \to K^+\pi^-\pi^-\pi^+$, $\overline{D}^0 \to K^0\pi^+\pi^-$ and $\overline{D}^0 \to K^+\pi^-\pi^0$. Fig. 3 shows the fitted mass distributions of $Kn\pi$ ($n = 1, 2, 3$) combinations. We totally accumulate $7696 \pm 199 \pm 369$ singly tagged neutral D meson sample. Fig. 4(a) and Fig. 4(b) show the distribution of the fitted masses of the $Kn\pi$ combinations for the events for which the $D^0 \to K^-e^+\nu_e$ and $D^0 \to \pi^-e^+\nu_e$ candidate events are observed in the system recoiling against the singly tagged $\overline{D}^0$. After subtracting numbers of background events (sideband background events and the background events due to other semileptonic or hadronic decays), 100.5 ± 10.2 and 10.3 ± 3.9 signal events for $D^0 \to K^-e^+\nu_e$ and $D^0 \to \pi^-e^+\nu_e$ decays are retained. We measure the branching fractions to be

$$BF(D^0 \to K^-e^+\nu_e) = (3.52 \pm 0.36 \pm 0.25)\%,$$

$$BF(D^0 \to \pi^-e^+\nu_e) = (0.36 \pm 0.14 \pm 0.03)\%.$$

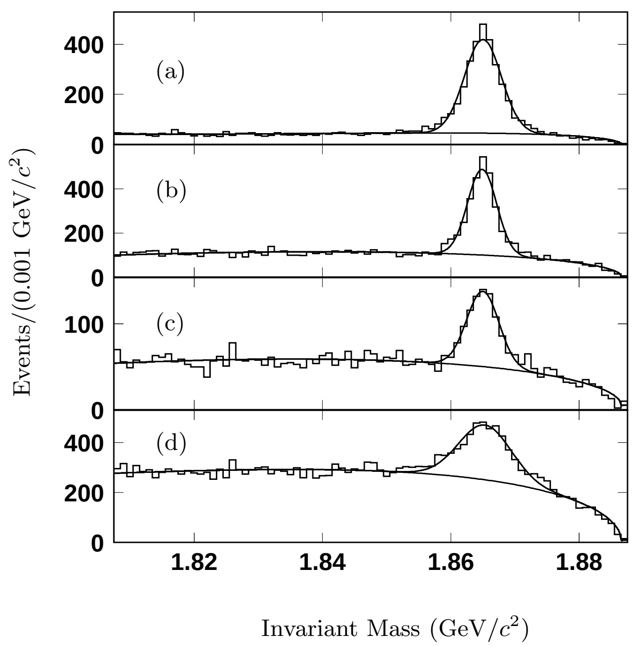

FIG. 3: Distributions of the fitted invariant masses of (a) $K^+\pi^-$, (b) $K^+\pi^-\pi^+\pi^-$, (c) $K^0_S\pi^+\pi^-$ and (d) $K^+\pi^-\pi^0$ combinations.

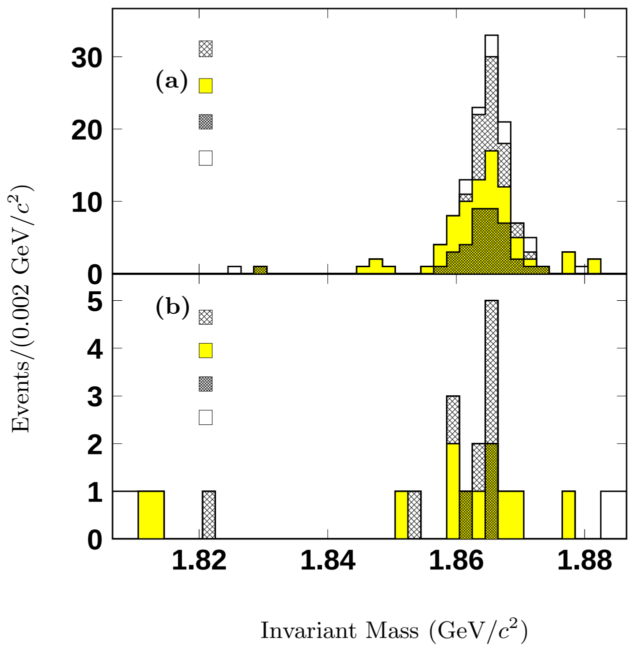

FIG. 4: Distributions of the fitted invariant masses of $Kn\pi$ combinations for the events for which (a) the $D^0 \to K^- e^+ \nu_e$ and (b) the $D^0 \to \pi^- e^+ \nu_e$ candidate events are observed in the system recoiling against the tagged $\overline{D}^0$.

B. Branching fraction for $D^+ \to \overline{K}^0 e^+ \nu$

Candidate events $D^+ \to \overline{K}^0 e^+ \nu_e$ is selected from the surviving tracks in the system recoiling against the tagged D^-. To select the $D^+ \to \overline{K}^0 e^+ \nu_e$ events, it is required that there are only three charged tracks, one of which is identified as an electron and the other two tracks as π^+ and π^-. The candidate events are required to satisfy the requirement $|U_{miss}| < 3\sigma_{U_{miss}}$, where the $\sigma_{U_{miss}}$ is the standard deviation of the U_{miss} distribution.

Fig. 5 show the distribution of the fitted invariant masses of the $Kn\pi$ combinations for the events for which the $D^+ \to \overline{K}^0 e^+ \nu_e$ candidate events are observed in the system recoiling against the singly tagged D^-. We measure the branching fraction to be

$$BF(D^+ \to \overline{K}^0 e^+ \nu_e) = (8.64 \pm 1.51 \pm 0.72)\%.$$

C. Form factors $f_+^\pi(0)$ and $f_+^K(0)$

The relations [4] [5] between the decay widths and the form factors are,

$$\Gamma(D^0 \to K^- e^+ \nu_e) = 1.53\ |V_{cs}|^2 |f_+^K(0)|^2 \times 10^{11} s^{-1}, \quad (4)$$

$$\Gamma(D^0 \to \pi^- e^+ \nu_e) = 3.01\ |V_{cd}|^2 |f_+^\pi(0)|^2 \times 10^{11} s^{-1}. \quad (5)$$

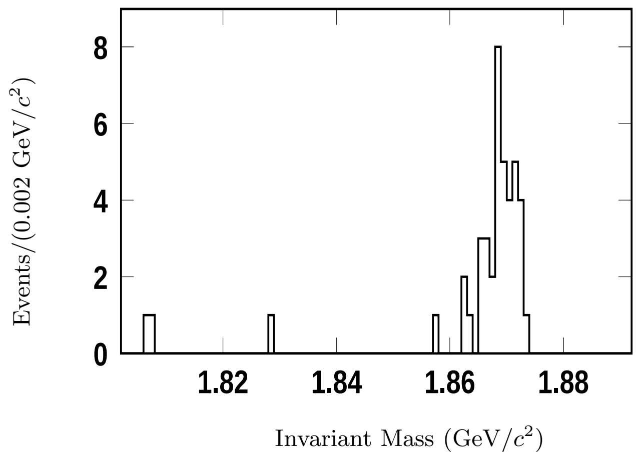

FIG. 5: Distributions of the fitted masses of $Kn\pi$ combinations for the events for which the $D^+ \to \overline{K}^0 e^+ \nu_e$ candidates are observed in the system recoiling against the tagged D^-.

The form factors $|f_+^K(0)|$ and $|f_+^\pi(0)|$ can be extracted by using the measured values of the branching fractions and the lifetime of the D^0 meson. Inserting the values of $|V_{cs}| = 0.996 \pm 0.013$, $|V_{cd}| = 0.224 \pm 0.016$ and the lifetime $\tau_D^0 = (411.7 \pm 2.7) \times 10^{-15}$ [2] into equation (4) and (5), the form factors are extracted to be $|f_+^K(0)| = 0.75 \pm 0.04 \pm 0.03$, $|f_+^\pi(0)| = 0.76 \pm 0.15 \pm 0.06$, where the first errors are statistical and the second are systematic. We extract the ratio of the two form factors to be

$$|f_+^\pi(0)/f_+^K(0)| = 1.01 \pm 0.20 \pm 0.08.$$

D. The ratio of $\Gamma(D^0 \to K^- e^+ \nu)/\Gamma(D^+ \to \overline{K}^0 e^+ \nu)$

Isospin symmetry predicts that the ratio of partial widths $\Gamma(D^0 \to K^- e^+ \nu)/\Gamma(D^+ \to \overline{K}^0 e^+ \nu)$ should be unity. The ratio can be obtained from the measured branching fractions for $D^0 \to K^- e^+ \nu$ and $D^+ \to \overline{K}^0 e^+ \nu$, and the lifetimes of the D^0 and D^+ mesons.

$$\frac{\Gamma(D^0 \to K^- e^+ \nu)}{\Gamma(D^+ \to \overline{K}^0 e^+ \nu)} = \frac{BF(D^0 \to K^- e^+ \nu)}{BF(D^+ \to \overline{K}^0 e^+ \nu)} \frac{\tau_{D^+}}{\tau_{D^0}}, \quad (6)$$

where the τ_{D^+} and τ_{D^0} are the lifetimes of D^+ and D^0 mesons. Inserting the measured branching fractions, and the lifetimes of the D^+ and D^0 mesons, we obtained the ratio to be

$$\frac{\Gamma(D^0 \to K^- e^+ \nu)}{\Gamma(D^+ \to \overline{K}^0 e^+ \nu)} = 1.04 \pm 0.21 \pm 0.08,$$

which is consistent with that the isospin conservation is held in D meson decays.

V. EVIDENCE OF $\psi(3770) \to J/\psi\pi^+\pi^-$

The $\psi(3770)$ resonance is believed to be a mixture of the 1^3D_1 and 2^3S_1 states of the $c\bar{c}$ system [6]. Since its mass is above open charm-pair threshold and its width is two orders of magnitude larger than that of the $\psi(2S)$, it is thought to decay almost entirely to pure $D\overline{D}$ [7]. However, recently some theoretical calculations point out that the $\psi(3770)$ could decay to non$-D\overline{D}$ final states [8] [9].

To search for the decay of $\psi(3770) \to J/\psi\pi^+\pi^-$, $J/\psi \to e^+e^-$ or $\mu^+\mu^-$, $\mu^+\mu^-\pi^+\pi^-$ and $e^+e^-\pi^+\pi^-$ candidate events are selected. These are required to have four charged tracks with zero total charge. Candidate events are subjected to four-constraint kinematic fits to either the $e^+e^- \to \mu^+\mu^-\pi^+\pi^-$ or the $e^+e^- \to e^+e^-\pi^+\pi^-$ hypothesis.

Fig. 6(a) shows the dilepton masses determined from the fitted lepton momenta of the accepted events. There are clearly two peaks. The lower mass peak is mostly due to $\psi(3770) \to J/\psi\pi^+\pi^-$, while the higher one is due to $\psi(2S) \to J/\psi\pi^+\pi^-$. Since the higher peak is produced by radiative return to the $\psi(2S)$ peak, its energy will be approximately 3.686 GeV, while the c.m. energy is set to the nominal energy in the kinematic fitting. Therefore, the dilepton masses calculated based on the fitted lepton momenta from $\psi(2S) \to J/\psi\pi^+\pi^-$, $J/\psi \to l^+l^-$ are shifted upward to about 3.18 GeV. The fit to this peak yields a J/ψ signal of 17.8 ± 4.8 events.

There is a contribution from $\psi(2S) \to J/\psi\pi^+\pi^-$ produced by radiative return to the tail of the $\psi(2S)$ that can pass the event selection criteria and yield fitted dilepton masses around 3.097 GeV. This is the main background to $\psi(3770) \to J/\psi\pi^+\pi^-$, as shown in Fig. 6(b). Here the histogram shows the dilepton mass distribution for $\psi(2S) \to J/\psi\pi^+\pi^-$ from our Monte Carlo simulation. The higher peak is due to the radiative return to the $\psi(2S)$ peak, and the lower peak is from radiative return to the tail of the $\psi(2S)$. The points with error bars show the total contribution from $\psi(2S)$ and $\psi(3770)$ production and decay. From the simulation, we estimate that $6.0 \pm 0.5 \pm 0.6$ out of 17.8 ± 4.8 events in the peak near 3.1 GeV in Fig. 6(a) are due to $\psi(2S) \to J/\psi\pi^+\pi^-$, where the first error is statistical and the second is the systematic arising from the uncertainty in the $\psi(2S)$ resonance parameters. The probability that the 17.8 events observed are due to a fluctuation of the 6.0 events is 3.8×10^{-4}.

After background subtraction, 11.8 ± 4.8 signal events are remained. The branching fraction for the non$-D\overline{D}$ decay $\psi(3770) \to J/\psi\pi^+\pi^-$ is measured to be

$$BF(\psi(3770) \to J/\psi\pi^+\pi^-) = (0.338 \pm 0.137 \pm 0.082)\%.$$

Using $\Gamma_{\rm tot}$ from the PDG [2], this branching fraction corresponds to a partial width of

$$\Gamma(\psi(3770) \to J/\psi\pi^+\pi^-) = (80 \pm 32 \pm 21) \ \ \text{keV}.$$

More detail may be found in Ref. [10] and Ref. [11].

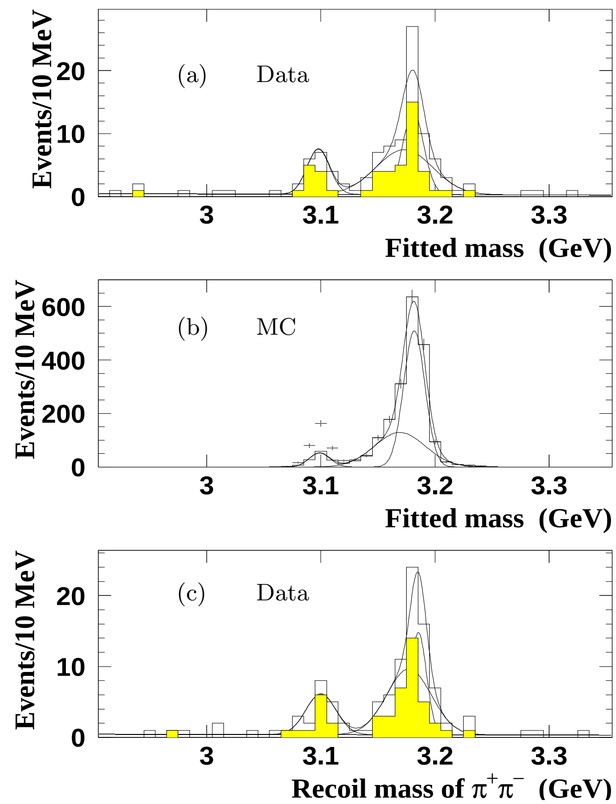

FIG. 6: Distributions of dilepton masses for (a) data and (b) Monte Carlo sample. The hatched histogram in (a) is for $J/\psi \to \mu^+\mu^-$, while the open one is for $J/\psi \to e^+e^-$. The histogram in (b) is for $\psi(2S) \to J/\psi\pi^+\pi^-$, while the points with error bars are the sum of $\psi(3770) \to J/\psi\pi^+\pi^-$ and $\psi(2S) \to J/\psi\pi^+\pi^-$. (c) Distribution of mass recoiling against the $\pi^+\pi^-$ system calculated using measured momenta for events that pass the kinematic fit requirement, where the hatched histogram is for $J/\psi \to \mu^+\mu^-$ and the open one is for $J/\psi \to e^+e^-$.

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